Miscellaneous Paper D-93-2
June 1993

US Army Corps of Engineers
Waterways Experiment Station

Long-Term Effects of Dredging Operations Program

Chronic Sublethal Effects of San Francisco Bay Sediments on *Nereis (Neanthes) arenaceodentata*; Full Life-Cycle Exposure to Bedded Sediments

by *David W. Moore, Thomas M. Dillon*
Environmental Laboratory

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Prepared for Headquarters, U.S. Army Corps of Engineers
and U.S. Army Engineer District, San Francisco

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Long-Term Effects of Dredging Operations Program

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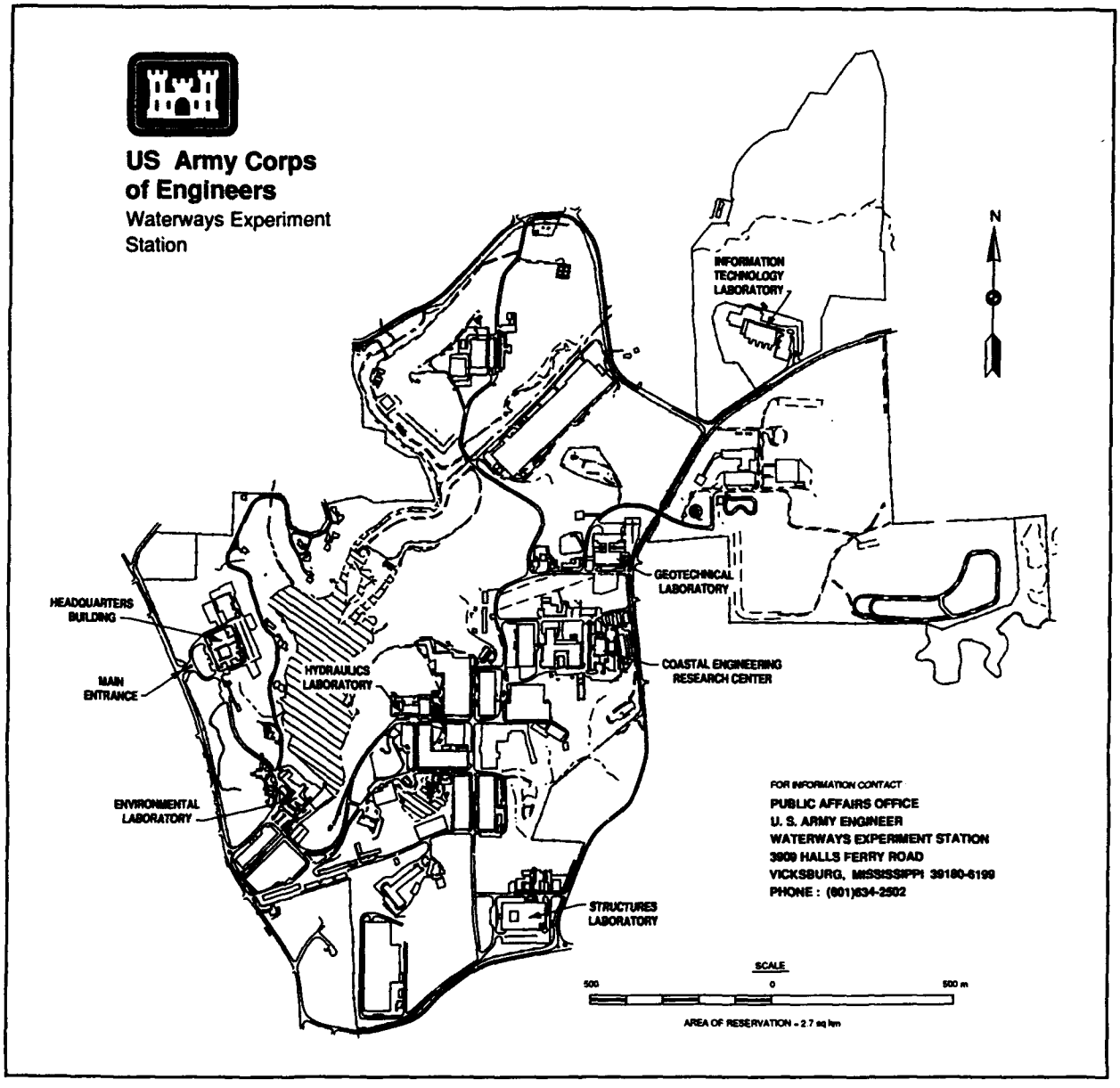
Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000
and U.S. Army Engineer District, San Francisco
San Francisco, CA 94105-1905



Waterways Experiment Station Cataloging-in-Publication Data

Moore, David W.
Chronic sublethal effects of San Francisco Bay sediments on Nereis (Neanthes) arenaceodentata : full life-cycle exposure to bedded sediments / by David W. Moore, Thomas M. Dillon ; prepared for U.S. Army Corps of Engineers and U.S. Army Engineer District, San Francisco.
52 p. : ill. ; 28 cm. — (Miscellaneous paper ; D-93-2)
Includes bibliographical references.
1. Marine sediments — California — San Francisco Bay. 2. Dredging spoil — California — Testing. 3. Nereis — Effect of pollution on. 4. Biological assay. I. Dillon, Thomas M. II. United States. Army. Corps of Engineers. III. United States. Army. Corps of Engineers. San Francisco District. IV. U.S. Army Engineer Waterways Experiment Station. V. Long-Term Effects of Dredging Operations Program (U.S.) VI. Title. VII. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; D-93-2.
TA7 W34m no.D-93-2

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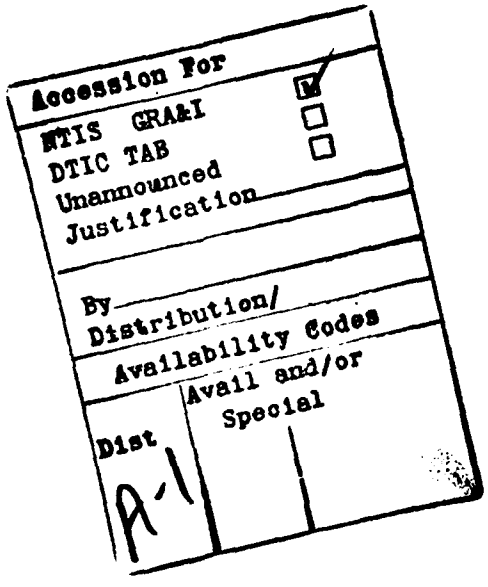

Preface

The work reported herein was conducted by the U.S. Army Engineer Waterways Experiment Station (WES) for Headquarters, U.S. Army Corps of Engineers (HQUSACE), and the U.S. Army Engineer District (USAED), San Francisco. Financial support was provided by the USAED, San Francisco, through an Intra-Army Order for Reimbursible Services. Additional funding was provided by HQUSACE through the Long-Term Effects of Dredging Operations (LEDO) Program, Work Unit 374-9 "Chronic Sublethal Effects." The LEDO Program is managed through the Environmental Effects of Dredging Programs, Dr. R. M. Engler, Manager.

This report was prepared by Drs. David W. Moore and Thomas M. Dillon, Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL) WES. The authors gratefully acknowledge the support provided by Mr. Thomas Chase, Mr. Kerry Guy, Ms. Sandra Lemlich, Mr. Duke Roberts, Dr. Thomas Wakeman, and Mr. Brian Walls of the San Francisco District. Dr. Gary Ray and Ms. Jerry Sims of the Coastal Ecology Branch, EL, provided technical assistance in the sorting of sediment samples.

The work was performed under the general supervision of Dr. Bobby L. Folsom, Jr., Chief, Fate and Effects Branch, EPED. The Chief of EPED was Mr. Donald L. Robey, and Director of EL was Dr. John Harrison.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

This report should be cited as follows:

> Moore, D. W., and Dillon, T. M. (1993). "Chronic sublethal effects of San Francisco Bay sediments on *Nereis (Neanthes) arenaceodentata*; Full life-cycle exposure to bedded sediments," Miscellaneous Paper D-93-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction

Background

San Francisco Bay is a highly altered estuary. Two major reasons are the diversion of freshwater inflow from the Sacramento-San Joaquin River systems and the loss of wetlands. By 1980, the amount of fresh water flowing into San Francisco Bay had been reduced by 60 percent. This reduction is projected to increase an additional 10 percent by the year 2000. About 95 percent of all freshwater/estuarine marshlands had been lost to land reclamation before 1850. It is not surprising, therefore, that the estuary has experienced a general decline in health and viability. One of the more noticeable symptoms of this decline has been the gradual loss of biological resources such as the striped bass and Pacific herring fisheries (Nichols et al. 1986).

An increase in the input of environmental contaminants has accompanied the physical alterations to San Francisco Bay. Major pollutant sources include the freshwater inflow from the Sacramento-San Joaquin River systems. Over 50 waste treatment plants and about 200 industries are permitted to discharge directly into the Bay (Luoma and Phillips 1988). Environmental contaminants discharged into aqueous systems tend to associate with particulate material in the water column and with bedded sediments. Periodically, bedded sediments must be removed to maintain navigable waterways. There is a concern that the relocation of these dredged materials may be having unacceptable adverse impacts on aquatic biota within the San Francisco Bay.

A large amount of sediment is dredged each year in San Francisco Bay. Approximately 5.5 million cubic meters (mcm) of sediment from Federal projects and permit actions are relocated annually. This value approximates the estimated average annual sediment inflow from natural sources of 6 to 8 mcm (U.S. Army Corps of Engineers (USACE) 1979). It has been estimated that 3.0 to 4.0 mcm of material leaves the Bay annually, while Central and North Bays experience a combined net accumulation of 4.2 mcm (USACE 1979). South Bay shows a net loss of nearly 0.8 mcm per year (Krone 1979). Despite these large numbers, the greatest yearly source of suspended sediment in San Francisco Bay is the resuspension of existing bottom material. Approximately 120 to 130 mcm of sediment are resuspended each year by

wind waves and currents (USACE 1979). The effect of these resuspended sediments on fish and aquatic invertebrates is unknown.

To examine whether San Francisco Bay dredged material was causing adverse biological effects, the Planning and Engineering Division of the USACE District, San Francisco, contracted with the Environmental Laboratory of the U.S. Army Engineer Waterways Experiment Station (WES) to develop and conduct a series of chronic sublethal sediment bioassays using material from selected sites within the Bay.

Regulatory History of Dredged Material Management in San Francisco Bay

To help define what is known regarding the potential toxicity of San Francisco Bay sediments, it is useful to first examine how dredged material has been regulated in the past. Important milestones in that process are shown in Table 1. It was recognized very early that San Francisco Bay is a physically dynamic system and that most dredged material disposal sites were dispersive. Consequently, initial management concerns were mostly operational. That is, efforts were directed towards optimizing dredging and disposal operations to minimize transportation costs and redredging.

Passage of the National Environmental Policy Act in 1970 outlined the Federal Government's policy toward the environment and signaled an increasing awareness for environmental protection in this country. That same year the San Francisco District initiated the Dredge Disposal Study (DDS) (USACE 1977). The DDS was a multifaceted interdisciplinary study designed, in part, to address some of the environmental concerns regarding potential impacts of dredge disposal operations. Although sediment toxicity was not examined directly, the physical impacts on biota (USACE 1975a) and the bioaccumulation of contaminants from dredged material were evaluated in laboratory and field studies (USACE 1975b; USACE 1975c). Those studies demonstrated the following:

a. Estuarine animals can survive suspended sediment loads in excess of those normally encountered during dredging and disposal.

b. In laboratory exposures to San Francisco Bay sediments, estuarine animals can bioaccumulate trace contaminants.

c. In field studies, contaminant tissue concentrations in animals near the disposal operations were not different from those far removed. The one exception was slightly elevated p,p'-DDE concentrations in mussels, *Mytilus edulis*, during disposal. These differences were not detected 1 month postdisposal.

Table 1
Milestones in the Regulation of Dredged Material in San Francisco Bay

1965	Committee on Tidal Hydraulics suggests that San Francisco District (CESPN) may be redredging a significant amount of material.
1970	Passage of National Environmental Policy Act.
1970	CESPN initiates Dredge Disposal Study. Terminated in 1975.
1972	CESPN reduces the number of in-bay disposal sites from 11 to 5.
1972	California RWQCB adopts USEPA's Jensen bulk sediment criteria. Material classified as "polluted" by these criteria was either placed upland or taken offshore to the 180-meter ocean disposal site.
1973	USACE initiates Dredged Material Research Program. Terminated in 1978.
1976	USACE publishes interim guidance for implementation of Section 404(b) of Public Law 92-500 (USACE 404 Manual).
1977	Publication of USEPA/USACE Ocean Disposal Implementation Manual.
1978	Public Notice 78-1 (PN 78-1) was drafted by the CESPN. Elutriate test procedures adopted from the Ocean Disposal Implementation Manual and in-bay disposal limited to three dispersive sites (Alcatraz, San Pablo Bay, and Carquinez Strait).
1980	California RWQCB adopts PN 78-1.
1980	100-fathom ocean disposal site becomes part of the Point Reyes-Farallon Islands Marine Sanctuary and is subsequently removed from the final designation process by USEPA.
1982	Mounding at the Alcatraz site noted in November.
1984	CESPN implements slurry policy to enhance dispersion during disposal.
1985	CESPN establishes the Disposal Management Program (DMP) to find operational solutions to disposal problems which are environmentally acceptable.
1985	San Francisco Bar Channel ocean disposal site receives final designation by USEPA. It can receive only coarse-grained material.
1988	Bioassay procedures used to evaluate Inner Oakland Harbor sediments under section 401 of the Clean Water Act.
1989	The Long-Term Management Strategy was initiated to reflect increasing regulatory and environmental concerns related to dredged material disposal in San Francisco Bay.
1991	Final revision of USEPA/USACE Ocean Disposal Implementation Manual.

In 1972, the California Regional Water Quality Control Board (RWQCB) adopted the Jensen criteria (Bowden 1977). These numerical criteria were developed by the U.S. Environmental Protection Agency (USEPA) for freshwater sediment in the Great Lakes and classified sediment as highly polluted, moderately polluted, or slightly polluted based on bulk sediment chemistry. As research on dredged material progressed, it became clear that these and other chemically based numerical criteria were technically inadequate because they did not assess either bioaccumulation potential or toxicity. Both

assessments were evaluated in bioassay procedures contained in the USEPA/ USACE Ocean Disposal Implementation Manual (USEPA/USACE 1977).

The San Francisco District adopted the use of bioassays for evaluating dredged material. Regulatory procedures were outlined in Public Notice (PN) 78-1. Elutriate procedures were emphasized since disposal sites in San Francisco Bay were generally dispersive. PN 78-1 also reduced the number of disposal sites from five to three. These were located in the Carquinez Strait, San Pablo Bay, and Alcatraz Island. To facilitate net export out of the Bay, most dredged material was taken to the Alcatraz disposal site.

In 1982, shoaling was noted at the Alcatraz site. As a result of this important development, the San Francisco District took several steps. The District instituted a slurry policy to enhance dispersion during disposal. It greatly reduced the amount of new dredged material taken to the Alcatraz site and even removed 30 tons (27,200 kg) of construction debris from the site. It monitored the physical configuration of the mound at Alcatraz and found it to be stable after two winter seasons. All of these actions led to the conclusion that the Alcatraz site could not be considered fully dispersive. Since the majority of dredged material in San Francisco Bay was taken to Alcatraz, a reduction in the capacity of that site represented a major impediment to maintenance dredging and to anticipated new work activities. The San Francisco District formed the Disposal Management Program (DMP) in 1985 and charged it with finding solutions to the disposal problem.

The Long-Term Management Strategy (LTMS) was initiated in 1989 to address increasing environmental concerns and to reflect the San Francisco District's commitment to a long-term management strategy for dredged material. In 1991, the Ocean Disposal Implementation Manual was revised to reflect 14 years of regulatory experience and the many scientific advances that had occurred since 1977 (USEPA/USACE 1991).

Overview of Sediment Toxicity Test Development in the United States

As indicated in the foregoing discussion, the regulation of dredged material disposal in San Francisco Bay has taken advantage of scientific advancements that have occurred elsewhere in the United States. To address concerns specific to the potential toxicity of San Francisco Bay sediments, it is important to have some general knowledge of advances in the field of sediment ecotoxicology. The following is not intended to be a comprehensive review per se; rather it is meant to provide the reader an overview of the advances that have occurred over the past 20 years.

The first peer-reviewed journal article that reported assessment of sediment toxicity was published in 1971 by Gannon and Beeton (1971) (Table 2). The laboratory procedure involved exposing amphipods to freshwater dredged

Table 2
Milestones in Scientific Development of Sediment Toxicity Tests

1971	Gannon and Beeton publish first journal article on sediment bioassays.
1973	USACE initiates Dredged Material Research Program.
1976	Publication of Priority Pollutant List by USEPA.
1976	Publication of USACE 404 Manual.
1977	Publication of USEPA/USACE *Ocean Disposal Implementation Manual*.
1978	DMRP completed.
1984	Pellston Conference on Fate and Effect of Sediment-Bound Chemicals.
1987	Formation of ASTM Subcommittee E47.03 on Sediment Toxicology.
1991	Final revision of USEPA/USACE Ocean Disposal Implementation Manual.

material that had been placed in modified milk cartons. In 1973, recognizing the need for a strong technical base in its regulatory program, USACE initiated the Dredged Material Research Program (DMRP). Included in the scope of this large program was the development of elutriate and solid phase bioassays to assess potential water column and benthic impacts, respectively (Saucier, Calhoun, and Engler 1978). The bioassays developed during the DMRP were subsequently incorporated into both the Ocean Disposal Implementation Manual (USEPA/USACE 1977) and the interim guidance manual for discharge of dredged or fill material into navigable waters (i.e., the 404 Manual) (USACE 1976). These sediment bioassays represented a balance between the state of the art and what could be routinely conducted in a regulatory program.

Prior to the mid-1970s, the scientific community expressed relatively little interest in sediment toxicity. Most of their energies were focused on the fate and effects of environmental contaminants dissolved in aqueous solutions. After the Priority Pollutant List was published in 1976, that emphasis shifted for two reasons. First, it was discovered that many chemicals on the Priority Pollutant List were not very soluble in water and, hence, were not bioavailable. Second, as more field data were gathered, it became apparent that concentrations of many contaminants on the Priority Pollutant List were much higher in the sediment than in the overlying water. Those findings led to initial speculation that sediments might be extremely toxic. However, subsequent research showed that the same forces causing chemicals to partition into the sediments also restricted their bioavailability to aquatic organisms.

A major milestone marking these scientific advances was the sixth Pellston Conference held in 1984 (Dickson, Mapi, and Brungs 1984). This was the first time leaders in the scientific community formally met to discuss the fate and effects of sediment-associated contaminants. Bioassay procedures contained in the 1977 USEPA/USACE Ocean Disposal Implementation Manual formed the basis for initial discussion. The researchers reached consensus

regarding sediment toxicity (Anderson et al. 1984). They recognized that species sensitivity was related, in part, to the degree of contact between sediment and organism. They recommended amphipods and mysid shrimp for lethal tests and polychaetes, bivalves, oligochaetes, and fish for behavioral or sublethal tests. There was also a strong endorsement of the Tiered Testing Approach for evaluating contaminated sediments (USEPA/USACE 1991). This approach eliminates unnecessary testing and directs limited resources to solving more urgent problems.

Another important milestone in the evolution of sediment toxicity methods occurred in 1987. Members of the American Society for Testing and Materials (ASTM) created a new subcommittee, E47.01 Sediment Toxicology. This subcommittee was charged with identifying technically sound procedures for evaluating sediment toxicity and with drafting appropriate standardized guideline documents. Guidelines, which are in various states of preparation, include the following:

a. Solid Phase Toxicity Tests with Freshwater Invertebrates.

b. Solid Phase Toxicity Tests with Marine Amphipods.

c. Solid Phase Toxicity Tests with Marine Polychaetes.

d. Solid Phase Bioaccumulation Tests with Invertebrates.

e. Solid Phase Bioaccumulation Tests with Fish.

f. Guidance for Designing Sediment Toxicity Tests.

g. Guidance for Collection, Storage, Characterization, and Manipulation of Sediment prior to Toxicity Testing.

When the USEPA/USACE Ocean Disposal Implementation Manual was first published in 1977, the procedures represented a balance between the state of the art and what could be achieved in the regulatory testing environment. It was realized at that time that revisions would have to be made to reflect scientific and regulatory advances. The manual has recently (1991) been revised. Significant improvements to the current manual as they relate to sediment toxicity evaluations include the following:

a. Formalizing the Tiered Testing Approach.

b. Refinements to the species selection process.

c. Provisions for evaluating chronic sublethal effects.

The assessment of chronic sublethal effects is treated as a Tier IV assessment and would be carried out only if there is a reason to believe chronic impacts may be occurring and if technically sound test protocols are available.

Scope

The objective of this report is to assess potential chronic sublethal toxicity of selected San Francisco Bay sediments. This report is not designed to be used in a regulatory decision-making process (i.e., 404 or 103); rather, it is intended to provide input to the District's DMP and LTMS for dredged material disposal in the San Francisco Bay area.

Test procedures for evaluating potential chronic sublethal effects of dredged material on aquatic biota have not been fully developed. Most suggested protocols are either water column tests that are ill-adapted for sediment or tests that utilize biological end points with little or no ecological relevance. Before the chronic sublethal effects of San Francisco Bay area sediments can be evaluated in a technically sound manner, a number of issues must be resolved including the following: (a) identification of appropriate test end points, (b) selection of a test organism, (c) development of test protocol, and (d) development of interpretative guidance.

In acute toxicity tests, generally only one end point is measured, percent survival. In contrast, a plethora of end points exists for sublethal tests. These end points may be categorized according to the level of biological organization they represent. In order of increasing complexity, these levels are as follows: molecular, cellular, tissue, organismic (whole animal), population, and community (Figure 1). When a sublethal effect occurs at any level of biological organization, mechanistic explanations may generally be found at lower levels, while ecological consequences are found at higher levels of complexity.

In the aquatic environment, the ultimate focus of environmental protection is the preservation of viable populations of organisms. Forecasting the potential impact at this level of biological complexity is difficult if not impossible. Bioassessments at lower levels of complexity (molecular-tissue) are possible, but their ecological relevance is uncertain. For these reasons, a surrogate toxicological bioassay approach is desirable. This approach, which examines whole animal (organismic) responses, represents a propitious balance between response sensitivity in the sublethal end point and ecological relevance of the results (Figure 1). Two of the most desirable end points for use in the surrogate toxicological bioassay approach are growth and reproduction. If reproductive success is impaired for a sufficient period of time, the viability of a population may be at risk. In addition, somatic growth and reproductive or gametic growth represent competing energy demands on the bioenergetics of aquatic animals. Therefore, if exposure to contaminated sediment is shown to reduce somatic growth, then reproductive success may also be adversely affected.

Both growth and reproduction are widely accepted end points in the scientific and regulatory community as ecologically relevant. The California RWQCB, for example, has identified growth as a highly desirable sublethal end point. The Board utilizes growth bioassays in its regulatory program for effluent applicants. Test results involving growth and reproduction have the

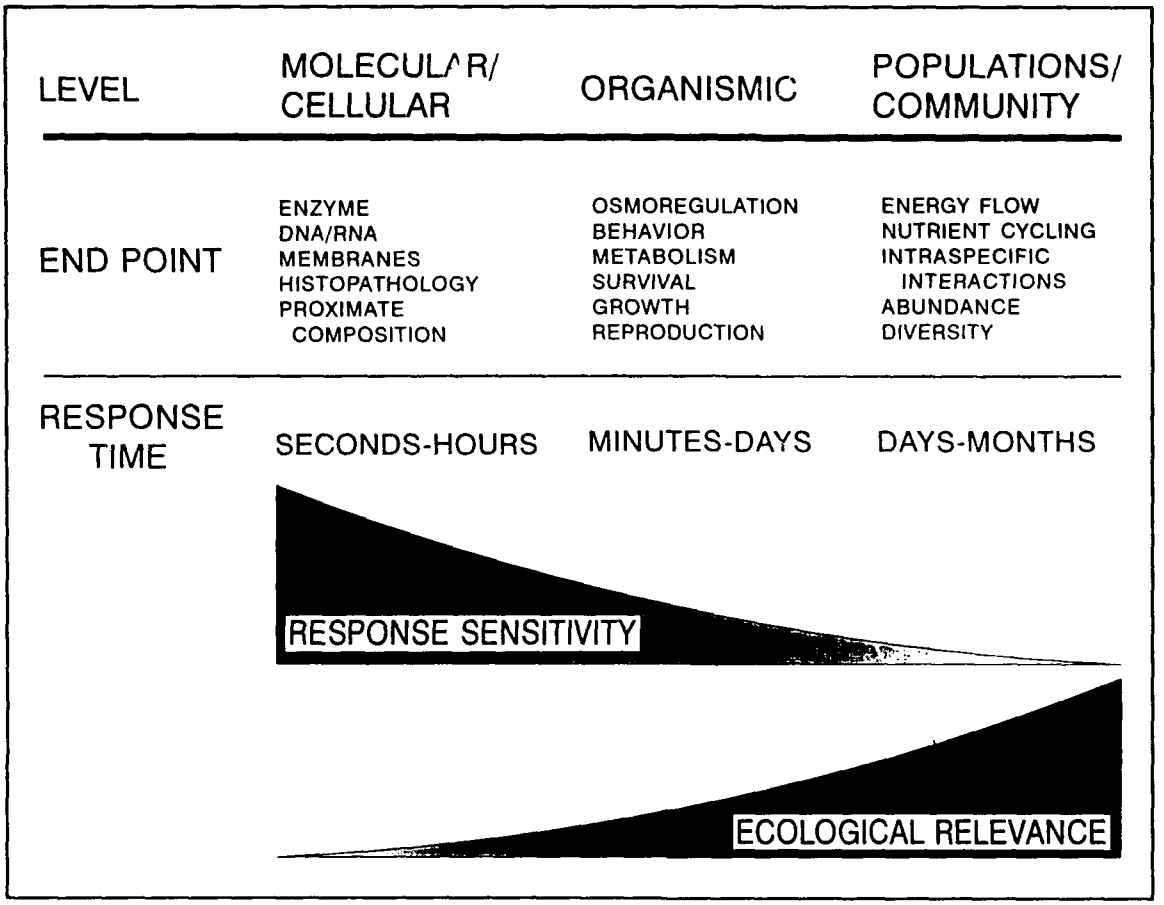

Figure 1. Sublethal end points within levels of biological organization

additional benefit of being generally understood and appreciated by a wider nontechnical audience. This latter characteristic is a very important consideration since data for large and/or controversial dredging projects will be carefully scrutinized by the public and, perhaps, the courts.

Selection of an appropriate animal model is another important step in developing a chronic sublethal sediment bioassay. The benthic infaunal polychaete worm *Nereis (Neanthes) arenaceodentata* will be used to evaluate chronic sublethal effects of San Francisco Bay sediments. Several features make this species particularly well suited for use in sediment toxicity tests. First, it maintains intimate contact with the sediment throughout its entire life cycle. Second, unlike many test organisms, *N. arenaceodentata* can be used to evaluate both solid phase and suspended phase material, allowing direct comparisons to be made between the two phases. Third, *N. arenaceodentata* is a sediment ingester. In both solid phase and suspended phase exposures, it readily ingests sediments while foraging for food and tube-building material. Fourth, it is well suited for monitoring of reproductive end points because, unlike most nereid polychaetes, it has no planktonic trochophore larvae. Instead, development is via metatrochophore larvae that are easier to observe

and manipulate from an experimental standpoint. Finally, because the whole life cycle can be completed in the laboratory, cultures producing test organisms of known age and background are possible. This is an attractive logistical characteristic from the perspective of regulatory testing.

Test protocols for a chronic sublethal sediment bioassay with *N. arenaceodentata* have already been developed for the Corps' Seattle District in cooperation with the State of Washington and Region X of the USEPA. A guide entitled "Guide for Conducting Acute and Chronic Sediment Toxicity Test with Polychaetous Annelids" is also currently under consideration by ASTM. Both of these tests are 20-day juvenile growth assays initiated with 3-week-old *N. arenaceodentata*. In addition, important nontreatment effects on survival and growth in *N. arenaceodentata* have been addressed in Moore and Dillon (1992).

To have regulatory utility, any chronic sublethal sediment bioassay must be accompanied by technically sound interpretive guidance. For *N. arenaceodentata*, this guidance must be able to answer the following question: "What diminution in growth is biologically important to *N. arenaceodentata*?" For example, if growth in Sediment A is statistically different from Sediment B by 15 percent, is that difference biologically important? What is the minimum required level of absolute growth (milligram dry weight) or growth rate (milligram dry weight day^{-1}) for *N. arenaceodentata*? Interpretative guidance for a growth end point has been provided previously (Moore and Dillon, "Chronic Sublethal Effects of San Francisco Bay Sediments on the Polychaete *Nereis (Neanthes) arenaceodentata*: Interpretative Guidance for the 21-Day Growth Bioassay").

In an earlier miscellaneous paper (Moore and Dillon, "Chronic Sublethal Effects of San Francisco Bay Sediments on *Nereis (Neanthes) arenaceodentata*: Partial Life-Cycle Exposure to Bedded Sediments"), survival, growth, and reproduction in *N. arenaceodentata* were evaluated after a 9-week exposure (i.e., from the emergent juvenile stage through pairing of sexually mature adults) to selected San Francisco Bay sediments. Results of that study suggested that two of the sediments (i.e., sediments from Alcatraz disposal site and Bay Farm Borrow Pit in South Bay) might be toxic to *N. arenaceodentata*. To further evaluate this potential toxic effect, the design of the original study was modified to examine survival, growth, and reproduction following a full life-cycle exposure (i.e., from the emergent juvenile stage through production of a second generation).

This report will focus on evaluating the chronic sublethal effects of selected San Francisco Bay sediments on the marine polychaete *N. arenaceodentata* following a full life-cycle exposure. Future reports will focus on interpretative guidance for reproduction, bioaccumulation, effects of food ration on test end points, effect of storage on sediment toxicity, and a discussion of quality assurance/quality control procedures for chronic sublethal sediment bioassays.

2 Material and Methods

Test Species

Nereis (Neanthes) arenaceodentata is a benthic infaunal polychaete widely distributed in shallow marine and estuarine benthic habitats of Europe, all three coasts of North America, and the Pacific (Reish 1957; Sanders et al. 1962; Reish 1963; Pettibone 1963; Reish and Alosi 1968; Day 1973; Gardiner 1975; Whitlatch 1977; Taylor 1984). This subsurface deposit-feeder constructs one or more mucoid tubes in the upper 2 to 3 cm of sediment and ingests sediment particles up to 70 μm with a preference for particles around 12 μm (Whitlatch 1980). *Nereis (Neanthes) arenaceodentata* has been accepted by the regulatory community as an appropriate test species for evaluating sediment (USEPA/ USACE 1977, 1991; Johns, Gutjahr-Gobell, and Schauer 1985). A considerable amount of toxicological information on a wide variety of environmental contaminants already exists for this species (Reish 1985; Jenkins and Mason 1988; Anderson et al. 1990).

Taxonomists are still debating the appropriate nomenclature for this species. Pettibone (1963), who suggested *Nereis (Neanthes) arenaceodentata*, lists five names in the synonomy for this species: *Spio caudatus, Nereis (Neanthes) caudata, Nereis arenaceodentata, Neanthes cricognatha,* and *Neanthes caudata*. Day (1973) dismissed *arenaceodentata* in favor of *acuminata*, which was subsequently used by Gardiner (1975), Taylor (1984), and Weinberg et al. (1990). *Neanthes arenaceodentata* is most commonly used in the toxicological literature. Recent evidence suggests that Atlantic and Pacific populations are genetically dissimilar, reproductively isolated, and are probably of different species (Weinberg et al. 1990). Until the taxonomic status of this species is resolved, the name most familiar to toxicologists will be used and the original source of worms will be reported.

The life cycle of *N. arenaceodentata* is well documented as are culture methods (Reish 1980). As worms approach sexual maturity, males and females establish pairs and occupy a common tube. Eggs are deposited by the female within the tube, and the male presumably fertilizes the eggs at this time. The spent female either exits the tube and dies within 1 to 2 days or is eaten by the male. The male remains in the tube to incubate and guard the

developing eggs. He creates a current of water via rhythmic undulations to remove metabolic waste and prevent hypoxic conditions.

Larval development is direct via nonplanktonic metatrochophore larvae and occurs entirely within the parental tube. Emergent juveniles (EJs) exit the parental tube about 3 weeks after egg deposition. They begin to feed and establish tubes of their own. Juvenile worms grow, and eggs become visible in the coelom of females about 6 weeks postemergence. Egg deposition follows 3 to 7 weeks later. The entire life cycle can be completed in the laboratory in 12 to 16 weeks at 20 to 22 °C. The nonplanktonic benthic larva and paternal care are unique among the Nereidae. This feature also facilitates laboratory culture and the experimental investigation of sublethal effects on growth and reproduction.

Laboratory Cultures

Stock populations of *Nereis (Neanthes) arenaceodentata* were obtained in March 1988 from Dr. D. J. Reish, California State University at Long Beach. Laboratory cultures were maintained using methods adapted from those described by Reish (1980) and Pesch and Schauer (1988). Briefly, EJs were raised to sexual maturity in 38-L aquaria containing 30 L of 30-ppt seawater (Instant Ocean) maintained at a temperature of 20 °C. The photoperiod was 12 hr light. Animals were fed a combination of ground Tetramarin flakes (2 mg/worm) and alfalfa (1 mg/worm) twice weekly. This feeding regime is sufficient to maintain adequate water quality in a static-renewal system and has been found to produce survival and reproduction consistent with that reported for other laboratory populations of *Neanthes* (i.e., survival >80 percent; fecundity, ca. 100 to 1,000 eggs/brood; EJ production, ca. 50 to 500 EJs/brood) (Reish 1980; Pesch et al. 1987; Anderson et al. 1990).

Seawater was renewed (80 percent of volume) every 3 weeks. This renewal schedule, based on water-quality monitoring data, is sufficient to maintain good water quality. After 10 weeks, worms were paired using the fighting response (Reish and Alosi 1968) and the presence or absence of eggs in the coelom. Unpaired worms were discarded. Pairs were placed in 600-ml beakers with 500 ml seawater. Gentle aeration was provided via Pasteur pipettes, and the beakers were covered with watch glasses to reduce evaporation. Water was carefully renewed weekly in a manner to avoid disturbing worm pairs.

Beakers were monitored daily for the presence of eggs and EJs. When discovered, EJs were mixed with other broods and returned to the 37-L aquaria to complete the culture cycle. These culture conditions and feeding rations were used in all experiments described below unless otherwise noted.

Test Sediments

Test sediments were collected from seven sites in the San Francisco Bay area. Test sediments fell into two categories: project sediments (collected from areas of proposed dredging) and reference sediments (selected to represent potential disposal areas). All test sediments were composites of several cores taken to project depth (38 ft (11.6 m) below mean low water mark) from a specific area. Reference sediments were collected from three potential in-bay disposal areas: on the mound at the Alcatraz disposal site (AMR), surrounding areas adjacent to the mound (AER), and the Bay Farm Borrow Pit in South Bay (BFR). An additional reference sediment was collected from an area outside the bay, Point Reyes (PRR), to represent a potential ocean disposal site. Project sediments were collected from three areas in Oakland Harbor: Oakland Inner Harbor (OI); Oakland Outer Harbor (OO); and from areas of Oakland Inner Harbor known to be contaminated, Oakland Contaminated (OC). In addition to the three project and four reference sediments, a control sediment from Sequim, WA, was also tested. This control sediment was essentially free of contamination and used to validate experimental results. Sediment collection was performed under the direction of Battelle Pacific Northwest Laboratory (for a complete description of sampling methods and protocols, see Mayhew et al., In Preparation). Coordinates for sampling locations may be found in Appendix A.

Sediment samples were immediately refrigerated (4 °C) on collection and shipped via a refrigerated truck to WES. Upon receipt at WES, sediment samples were wet sieved (<2mm), thoroughly homogenized, and refrigerated (4 °C) until analysis and testing could be performed. Three composites from each of the eight sediments were analyzed for priority pollutant metals (except antimony and thallium), chlorinated pesticides and polychorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Analysis was performed by the Analytical Laboratory Group (ALG) at WES according to procedures outlined in USEPA SW-846 (USEPA 1986). Sediments were also analyzed for tributyltins, dibutyltins, and monobutyltins by the Naval Command and Control and Ocean Surveillance Center in San Diego, CA, using procedures outlined by Stallard, Cola, and Dooley (1989). Total organic carbon (TOC) and Total Kjeldahl nitrogen (TKN) analyses were performed by the ALG using Standard Method 505c (Standard Methods for the Examination of Water and Wastewater 1989) and procedures outlined in USEPA (1979), respectively. Grain size analysis was performed using the methods of Patrick (1958). Percent loss of volatile solids after ignition (LOI) was determined using Standard Methods 209a and 209c (Standard Methods for the Examination of Water and Wastewater 1989). In addition, pore water was extracted from each of the sediments using methods described by Ankley, Katko, and Arthur (1990). Sediment pore water extracts were subsequently analyzed for total NH_3 and H_2S. Samples for ammonia analysis were adjusted to a pH of 2 with 1 *N* HCL and stored at 4 °C for no longer than 2 weeks. Total ammonia (milligrams/liter) was determined with an Orion ammonia-specific electrode after adjusting sample pH to 12 with 5 *N* NaOH. Pore water extracts were

analyzed for H_2S using a HACH HS-7 test kit. This kit makes use of the color reaction between lead acetate and hydrogen sulfide. Filter pads impregnated with lead acetate are exposed to effervescing water samples containing hydrogen sulfide. The ensuing color change in the filter pad is compared with a standardized chart accompanying the kit to yield a semiquantitative measurement of hydrogen sulfide. Results of chemical analysis, TOC determinations, TKN, grain size, and pore water analysis are found in Appendix B. Additional information on detection limits, instrumentation, and quality assurance protocols for analysis performed by the ALG can be found in Strong and Myers (1991).

Experimental Approach

Sediments were evaluated in full life-cycle exposures with the marine polychaete *Nereis (Neanthes) arenaceodentata*. Sediments were added to 38-L aquaria to a depth of 2.5 cm. Thirty liters of 30-ppt salinity seawater was gently added to each aquarium, carefully avoiding resuspension of the bedded sediment. To initiate the test, emergent juvenile worms (n = 2,400) were taken from laboratory culture and randomly distributed among 24 aquaria. There were three aquaria/sediment type and 100 EJs/aquarium. This stocking density has been found to provide optimal growth and development of *N. arenaceodentata*. The test was conducted under static-renewal conditions (renewal every 3 weeks) at a temperature of 20 °C and a 12-hr photoperiod. Gentle aeration was provided to each aquaria. Worms were fed twice weekly a combination of finely ground Tetramarin and alfalfa prepared in a seawater slurry. Worms were exposed to test sediments for 9 weeks. Dissolved oxygen, salinity, temperature, and pH were monitored weekly. In addition, a 30-ml sample was collected from each aquarium, fixed with 50 μl of 1 *N* HCL, refrigerated, and subsequently analyzed for total ammonia by methods previously described for analysis of total ammonia in sediment pore water.

After 9 weeks, worms were removed from all aquaria and counted. Effects on growth were evaluated by measuring the wet weights of all worms including those individual worms used to establish reproductive pairs (see below). Each worm was briefly rinsed in seawater, placed on tared aluminum pans, and weighed to the nearest 0.01 mg on an electrobalance.

Effects on worm reproduction were evaluated by establishing mated pairs (*n* = 40) from each treatment and monitoring egg deposition and production of EJs. Sex was confirmed by the presence of eggs in the coelom and the fighting reaction described by Reish and Alosi (1968). Mated pairs were placed in 600-ml beakers containing approximately 200 ml of bedded test sediment with 300 ml of overlying 30-ppt saltwater. Beakers were covered with watch glasses and provided trickle flow aeration. Animals were fed a Tetramarin-alfalfa slurry to provide enough material for initial foraging and tube-building activity. Pairs were not fed for the remainder of the test since feeding activity is greatly reduced prior to egg deposition and during brood

incubation (Pesch and Schauer (1988), personal observation). Approximately 80 percent of the seawater was renewed in each beaker on a weekly basis. Prior to renewal, water quality (dissolved oxygen, salinity, temperature, and pH) was recorded for randomly selected beakers in each treatment group. In addition, a 30-ml sample was collected, fixed with 50 μl of 1 *N* HCL, refrigerated, and subsequently analyzed for total ammonia.

Once pairs had been established, all beakers were observed daily for egg masses and/or females that had recently deposited and EJs. Although pairs construct tubes in the test sediment, generally these tubes were in contact with the beaker walls making observation of egg masses possible. Female *Neanthes* die shortly (within 1 or 2 days) after deposition. Following deposition, the female becomes pale green in color and generally exits the tube to the sediment surface. In this manner, egg deposition was identified through either direct observation of an egg mass in the parental tube or indirectly via appearance of the female. When an egg mass was discovered, the date of deposition was recorded. Beakers were terminated when EJs with food in their gut appeared outside the parental tube and/or small pin-sized burrows were observed in the sediment surface indicating the presence of EJs. Beakers were terminated by carefully decanting overlying water, taking care not to disturb the test sediments or lose any EJs. The bedded sediment including surviving organisms was then transferred to 300-ml polypropylene screw top sample containers and preserved with approximately 100 ml of 10 percent buffered formalin containing rose bengal. The preserved sediments were subsequently sorted and the number of EJs recorded. *Monitoring* for egg deposition and EJ production continued for 10 weeks (Figure 2).

Statistical Analysis

All statistical analysis and data transformation were conducted using SYSTAT statistical software (Wilkinson 1988). All data were screened for normality and homogeneity of variance prior to statistical analysis. Normality was confirmed by plotting the values of the variable against the corresponding percentage points of a standard normal variable (Sokal and Rohlf 1981). Homogeneity of variance was evaluated via Bartlett's test. As a result of these data screening procedures, all wet weights were log transformed to normalize the data prior to statistical analysis. Treatment effects were analyzed using analysis of variance with subsequent mean separation via Tukey's HSD (Honestly Significant Difference) test (Sokal and Rohlf 1981). All tests for significance were analyzed at a significance level of $\alpha = 0.05$.

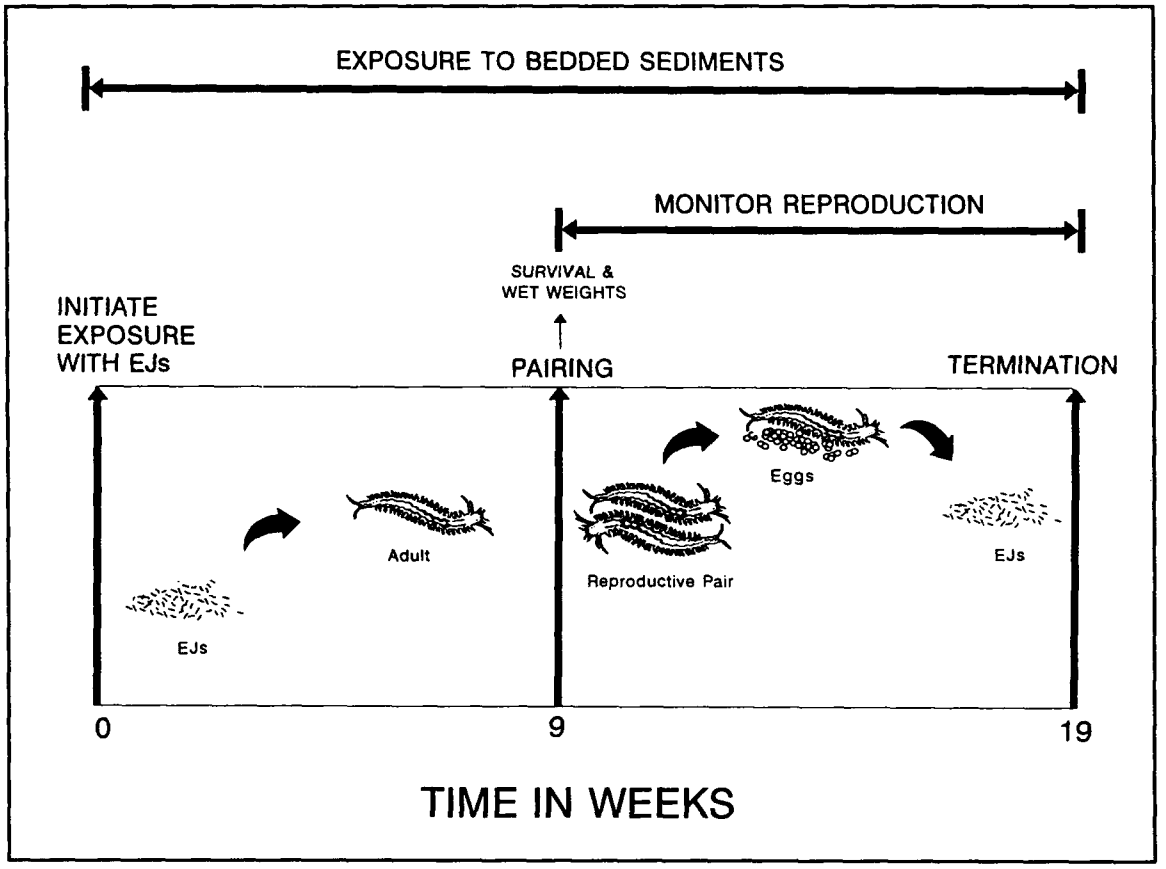

Figure 2. Experimental timetable for exposure of *Neanthes* to bedded sediments from selected areas within and around San Francisco Bay

3 Results

Test Sediments

Grain size analysis indicated that AMR, PRR, AER, and OI sediment was mostly sand (ie., >50 percent sand), while BFR, OC, OO, and Sequim control (SC) sediments were fine grained (ie., mostly silt and clay). Percent LOI mirrored the gradient observed for grain size analysis with the finer grained sediments having much higher levels of combustible organic matter. Results of organic carbon content were far more variable than percent LOI with nearly a five-fold difference among replicate measures for a single sediment. The lowest levels of organic carbon were measured in OI sediment (eg., 0.03 to 0.15 percent TOC), while the highest levels were measured in SC sediment (eg., 0.42 to 0.84 percent TOC). TKN was markedly higher in SC sediment (ca. 3,500 mg/kg) relative to all other sediments tested (10 to 500 mg/kg).

Analysis of sediment pore water extracts also showed marked difference between sediment types. Analysis of pore water for total ammonia resulted in a gradient in NH_3 concentrations ranging from ca. 5 mg/L in AER sediment pore water to ca. 40 mg/L in OC sediment pore water. High levels of hydrogen sulfide were measured in the pore water of SC sediment, while it was not detected in any of the other sediment types tested.

Results of chemical analysis for each of the sediment types suggest a common trend. Concentrations of metals, butyltins, and PAHs were several times higher in OC sediments when compared with the other San Francisco Bay sediments and SC. Significant concentrations of pesticides or PCBs were not found in any of the sediments tested.

Survival and Growth

After 9 weeks exposure, EJs were observed in nearly every sediment treatment. Therefore, accurate determinations of survival were not possible. Growth measured as individual wet weight was significantly reduced in all treatments (except for OI) relative to the controls (i.e., SC) (Figure 3,

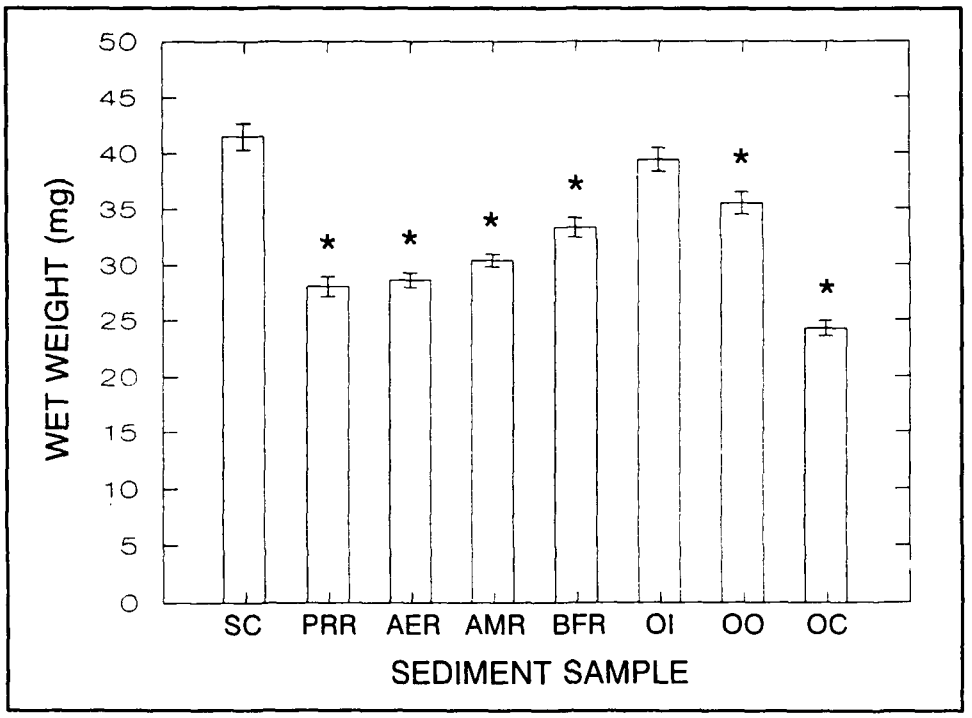

Figure 3. Effect of San Francisco Bay sediment on mean individual wet weight (in milligrams) of *Neanthes*. Error bars = standard error of the mean. Asterisk indicates significant difference relative to the SC control at $p < 0.05$

Table 3). A similar trend was observed when wet weights of only those animals selected for reproducing pairs were compared (Figure 4, Table 3).

Reproduction

Percent reproduction was high in all treatments ranging from 75 percent in the AER treatment to 95 percent in the PRR treatment (Figure 5, Table 3). Worms exposed to San Francisco Bay sediments produced significantly fewer EJs relative to control animals (Table 3). EJ production in worms exposed to PRR sediments was not significantly different from controls. When only reproducing pairs were considered, all treatments produced significantly fewer EJs relative to controls (Figure 6, Table 3). Though there were no statistical differences in the timing of reproductive events (Figure 7), the mean time from pairing to appearance of EJs was shorter in control animals (40 days) relative to all other treatments (45 to 50 days).

Water Quality

Water quality was good in all sediment exposures (Appendix C).

Table 3
Effect of San Francisco Bay Sediments on Growth and Reproduction in *Neanthes*

Life-history Trait	Sediment Sample							
	SC	PRR	AER	AMR	BFR	OI	OO	OC
Wet Weight, mg								
All animals	A	B	B	B	C	A	C	D
	42	28	29	30	33	39	35	24
	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
Reproductive pairs[1]	A	B	C	C	B	D	D	C
	59	41	38	38	43	51	47	37
	(2)	(1)	(1)	(1)	(1)	(1)	(2)	(1)
EJ production								
All pairs	A	B	C	C	C	C	C	C
	219	179	111	121	123	127	134	105
	(17)	(11)	(17)	(15)	(12)	(14)	(16)	(11)
Reproducing pairs only	A	B	BC	C	C	BC	BC	C
	243	189	148	138	141	154	163	121
	(14)	(9)	(11)	(8)	(11)	(13)	(15)	(11)
Reproducing pairs[2]	AB	A	B	AB	AB	AB	AB	AB
	90	95	75	87	87	82	82	87

Note: Means under the same letter are not significantly different ($p < 0.05$). EJ = Emergent Juvenile worms.
[1] Mean individual wet weight of only those animals selected for reproductive pairs (N = 80).
[2] Percent of pairs producing EJs (N = 40).

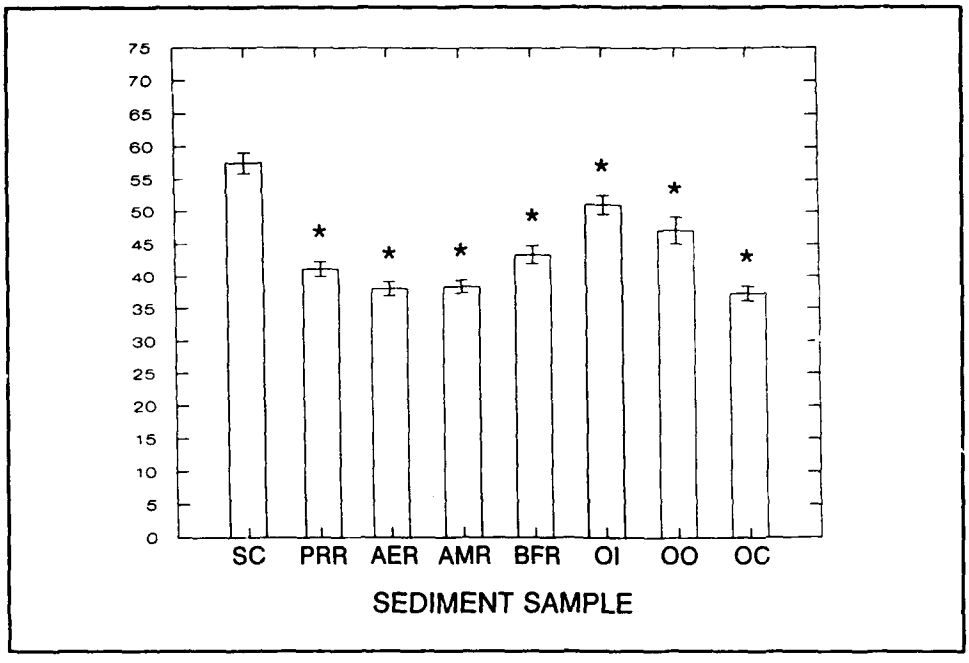

Figure 4. Effect of San Francisco Bay sediment on mean individual wet weight (in milligrams) of *Neanthes* (animals selected for reproductive pairs only). Error bars = standard error of the mean. Asterisk indicates significant difference relative to the SC control at $p < 0.05$ (N = 80)

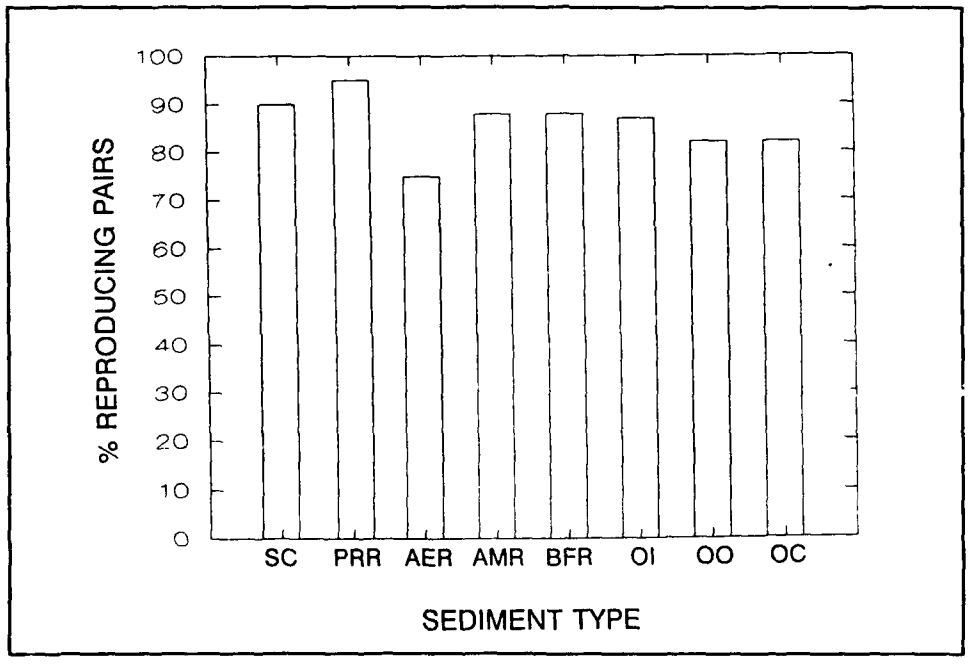

Figure 5. Effect of San Francisco Bay sediment on the percentage of reproducing pairs of *Neanthes* (N = 40)

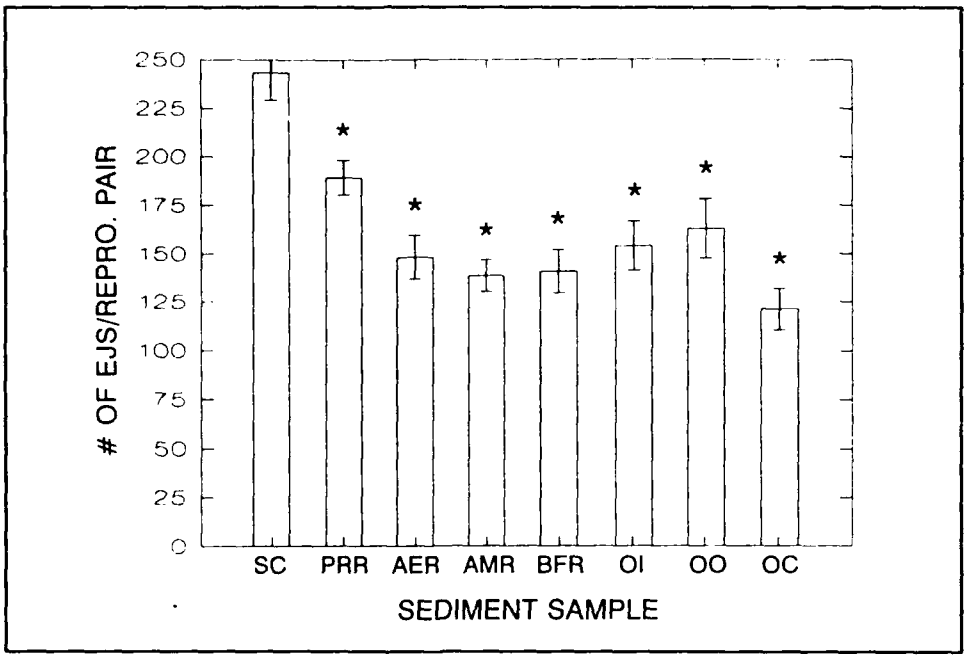

Figure 6. Effect of San Francisco Bay sediment on mean EJ production (reproducing pairs only) in *Neanthes*. Error bars = standard error of the mean (N = 20)

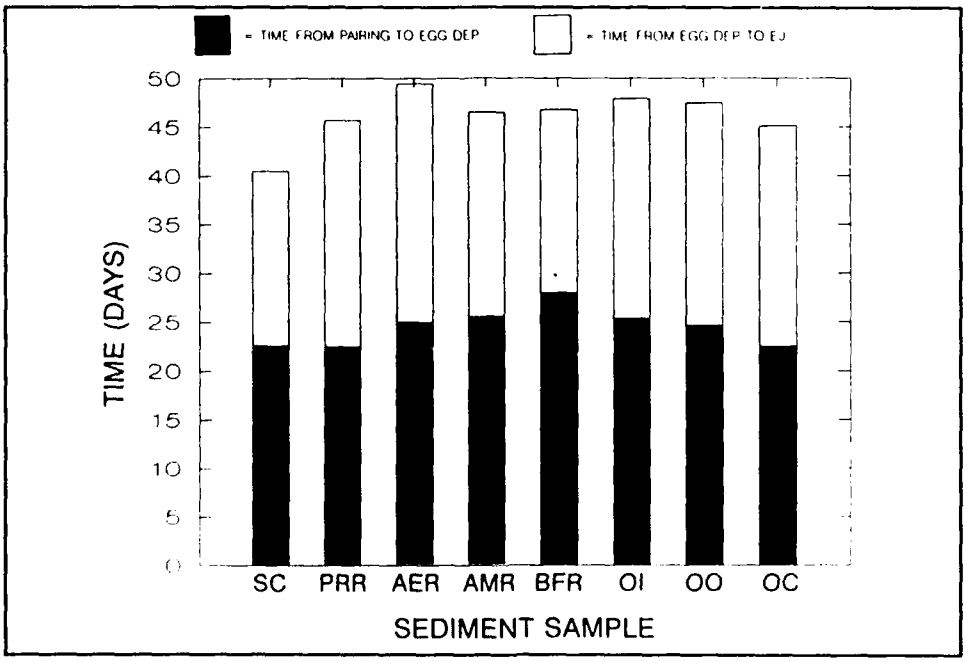

Figure 7. Effect of San Francisco Bay sediment on timing of reproductive events in *Neanthes*

4 Discussion

After 9 weeks exposure, EJs were found in all of the test sediments indicating reproduction had occurred. As a consequence of this early reproduction, an accurate determination of survival was not possible. Growth measured as wet weight was significantly reduced in worms exposed to all sediments (except OI) relative to the controls. One possible explanation for the observed reduction in growth is the poor nutritive value of the test sediments relative to the control sediment. Marsh, Gremare, and Tenore (1989) and Tenore (1977) have found that growth of the polychaete *Capitella capitata* increased with increasing nitrogen concentration of different food sources. Taghon and Greene (1990) also found a positive correlation between growth in the polychaete *Abarenicola pacifica* and the labile nitrogen concentration of sediments. Results for TKN (Appendix B) indicate that all the test sediments were nitrogen poor (i.e., 1 to 2 orders of magnitude lower) relative to the SC control sediment. However, poor nutritive value provides only a partial explanation since animals exposed to OI sediments (which were also nitrogen poor) were not statistically different in terms wet weight from the controls (Figure 3). This discrepancy might have occurred because contaminant/contaminants were not included in the chemical analysis or possibly because of qualitative differences between sediment types in terms of some physicochemical characteristic (e.g., an essential nutrient).

Reproduction was significantly reduced in all test sediments (except PRR) relative to the controls (Table 3). The high percentage of pairs that reproduced (75 to 95 percent) (Figure 5) and the observed differences in EJ production among reproducing pairs (Figure 6) indicate that the reduced reproduction was a function of reproductive output rather than frequency of mating success. Reduced EJ production in worms exposed to San Francisco Bay sediments may have resulted from reduced fecundity, fertilization, and/or direct effects of the sediment on gamete or larval viability.

Any one of these processes may have been the mode of action by which exposure to test sediment reduced reproduction in *Neanthes*. These experiments were not designed to assess the potential influence of any of these factors. However, results of other investigations allow speculation on their possible importance. For example, oocytes may not have been viable following deposition. Diet has been shown to effect significant differences in the fatty acid and sterol composition of eggs in the polychaete *Capitella* sp I

(Marsh et al. 1990). Fatty acids and sterols are critical to determining the structure and function of cell membranes. Consequently changes in oocyte composition may result in altered viability and influence larval growth and survival. Lowered energy reserves resulting from reduced somatic growth may have lead to lower reproductive output. A previous study (Moore and Dillon, "Chronic Sublethal Effects of San Francisco Bay Sediments on the Polychaete *Nereis (Neanthes) arenaceodentata*: Interpretative Guidance for the 21-Day Growth Bioassay"), reported that reductions in somatic growth in the polychaete *Neanthes (nereis) arenaceodentata* resulted in reduced fecundity and EJ production. Fertilization may have been less than 100 percent. It has recently been suggested that a breakdown at the sperm transfer stage is the cause of reproductive isolation observed among geographically separated populations of two polychaete species, *Polydora ligni* and *Streblospio benedicti* (Rice 1991). In preliminary experiments on interpopulation sperm transfer with the polychaete *Polydora*, Rice found that sperm were not reaching the sperm storage organs of the female. This suggests a potential for disruption of the fertilization process by effecting the chemical cues necessary to guide sperm to the seminal receptacle and/or effecting female receptivity to accept the male spermatophores. In addition, male *Neanthes* are known to ingest eggs and developing larvae during the incubation period (Pesch and Schauer, 1988 personal observation). All these factors may even be related. It may be that the male ingests dead or dying eggs/larvae for "housekeeping" purposes (i.e., to reduce the chance of fungal infection and ensure survival of the remaining viable eggs/larvae).

Results of this study indicate that exposure of *Nereis (Neanthes) arenaceodentata* to San Francisco Bay sediment results in lower mean wet weights and reduced reproductive output. Extensive chemical analysis failed to provide an explanation for these impacts. TKN values seem to account for some but not all of the observed differences. Whether these differences resulted from contaminant/contaminants not included in our chemical analysis and/or some other physico-chemical characteristic of the sediments is not known.

5 Conclusions

Conclusions based on this study are summarized below.

- Chronic full life-cycle sediment exposures were conducted with the polychaete worm *Nereis (Neanthes) arenaceodentata* and seven San Francisco Bay area sediments. Test end points were growth and reproductive success.

- Wet weights of *Nereis (Neanthes) arenaceodentata* exposed to all test sediments were significantly depressed relative to wet weights of worms exposed to the control sediment (SC). TKN values for the SC control sediments were 1 to 2 orders of magnitude higher than all other test sediments.

- Reproduction was significantly reduced in all test sediments relative to the SC control sediment.

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Appendix A
Sediment Sampling Locations

Sediment Sample[1]	Sampling Station[2]	Date Sampled	Latitude/Longitude Coordinates North (Y)East (X)	
SC	SEQUIM	09-OCT-90	48° 03.68′	123° 01.33′
PRR	R-PF-1	09-OCT-90	37° 52.24′	123° 01.47′
PRR	R-PF-2	09-OCT-90	37° 52.30′	123° 01.53′
PRR	R-PF-3	09-OCT-90	37° 52.20′	123° 01.45′
PRR	R-PF-4	09-OCT-90	37° 52.31′	123° 01.41′
PRR	R-PF-5	09-OCT-90	37° 52.22′	123° 01.52′
PRR	R-PF-6	09-OCT-90	37° 52.35′	123° 01.38′
AER	R-AC-8	10-OCT-90	37° 49.12′	122° 25.15′
AER	R-AC-5	10-OCT-90	37° 49.23′	122° 25.15′
AER	R-AC-2	10-OCT-90	37° 49.17′	122° 25.32′
AER	R-AC-1	10-OCT-90	37° 49.23′	122° 25.32′
AMR	R-AM-A	09-OCT-90	37° 49.87′	122° 25.95′
AMR	R-AM-D	09-OCT-90	37° 49.08′	122° 26.39′
AMR	R-AM-G	09-OCT-90	37° 48.88′	122° 25.89′
AMR	R-AM-H	09-OCT-90	37° 48.99′	122° 25.53′
AMR	R-AM-I	09-OCT-90	37° 49.02′	122° 25.00′
AMR	R-AM-F	09-OCT-90	37° 49.45′	122° 24.88′
AMR	R-AM-C	09-OCT-90	37° 49.98′	122° 24.96′
AMR	R-AM-B	09-OCT-90	37° 49.85′	122° 25.46′
AMR	R-AM-B	09-OCT-90	37° 49.80′	122° 25.37′
BFR	R-BF-2	10-OCT-90	37° 44.08′	122° 25.15′
BFR	R-BF-4	10-OCT-90	37° 44.68′	122° 16.55′
BFR	R-BF-5	10-OCT-90	37° 44.50′	122° 16.15′
BFR	R-BF-3	10-OCT-90	37° 44.41′	122° 16.82′

[1] WES sample designation (see Material and Methods).
[2] Battelle site designation.

Sediment Sample[1]	Sampling Station[2]	Date Sampled	California State Plane Coordinates (Zone III)	
			North (Y)	East (X)
OI	I-C-1	11-OCT-90	479980	1467348
OI	I-C-2	11-OCT-90	480130	1467924
OI	I-C-3	11-OCT-90	478901	1469592
OI	I-C-4	09-OCT-90	478089	1471461
OI	I-C-5	10-OCT-90	476668	1474646
OI	I-C-6	09-OCT-90	475924	1477730
OI	I-C-7	10-OCT-90	475758	1480197
OI	I-C-8	10-OCT-90	475480	1481316
OI	I-C-9	10-OCT-90	475689	1482348
OI	I-C-10	09-OCT-90	475763	1482877
OI	I-C-11	09-OCT-90	475881	1483336
OI	I-C-12	09-OCT-90	475893	1483805
OI	I-C-13	09-OCT-90	475924	1484255
OI	I-C-14	09-OCT-90	475859	1485008
OI	I-C-15	09-OCT-90	475721	1485693
OI	I-C-16	09-OCT-90	475925	1485720
OI	I-C-17	09-OCT-90	476074	1485721
OI	I-C-18	09-OCT-90	475614	1486540
OO	O-C-1	08-OCT-90	479279	1464190
OO	O-C-2	08-OCT-90	480332	1465026
OO	O-C-3	08-OCT-90	480671	1565949
OO	O-C-4	08-OCT-90	481289	1467347
OO	O-C-5	08-OCT-90	482470	1469706
OO	O-C-6	08-OCT-90	483881	1471338
OO	O-C-7	08-OCT-90	483549	1472330
OO	O-C-8	08-OCT-90	482532	1473381
OO	O-C-9	08-OCT-90	483539	1474561
OO	O-C-10	08-OCT-90	484727	1475200
OO	O-C-11	08-OCT-90	486135	1475973
OO	O-C-12	08-OCT-90	485732	1476500
OO	O-C-13	08-OCT-90	485744	1477684
OC	I-M-1	09-OCT-90	476363	1485762
OC	I-T-6	09-OCT-90	475357	1483653

[1] WES sample designation (see Material and Methods).
[2] Battelle site designation.

Appendix B
Physical and Chemical Analysis of Sediment Samples

Sediment Sample	REP	Grain Size Distribution		
		Sand, percent	Silt, percent	Clay, percent
SC	1	13.0	40.0	47.0
SC	2	13.0	40.0	47.0
SC	3	13.0	40.0	47.0
PRR	1	60.0	27.5	12.5
PRR	2	60.0	30.0	10.0
PRR	3	57.5	30.0	12.5
AER	1	50.0	35.0	15.0
AER	2	60.0	30.0	10.0
AER	3	55.0	32.5	12.5
AMR	1	65.0	25.0	10.0
AMR	2	70.0	24.0	6.0
AMR	3	67.5	25.0	7.5
BFR	1	17.5	55.0	27.5
BFR	2	10.0	57.0	33.0
BFR	3	17.5	55.0	27.5
OI	1	52.5	32.5	15.0
OI	2	55.0	32.5	12.5
OI	3	55.0	32.5	12.5
OO	1	28.0	50.0	22.0
OO	2	28.0	50.0	22.0
OO	3	28.0	47.5	24.5
OC	1	20.0	52.5	27.5
OC	2	20.0	55.0	24.5
OC	3	17.5	52.5	30.0

Sediment Sample[1]	REP	Moisture percent	LOI percent	TOC percent	TKN, mg/kg
SC	1	66	14.485	0.841	3960
SC	2	62	13.818	0.816	2920
SC	3	66	13.600	0.422	3740
PRR	1	28	3.509	0.430	389
PRR	2	27	3.400	0.484	427
PRR	3	27	3.341	0.415	511
AER	1	33	5.149	0.552	401
AER	2	33	5.022	0.419	346
AER	3	33	4.837	0.608	348
AMR	1	15	0.858	0.539	24
AMR	2	15	0.770	0.517	N.D.[2]
AMR	3	16	0.950	0.355	N.D.
BFR	1	54	9.068	0.156	454
BFR	2	54	9.105	0.666	680
BFR	3	54	9.638	0.452	485
OI	1	26	3.807	0.152	110
OI	2	26	3.955	0.032	136
OI	3	26	3.439	0.067	211
OO	1	42	7.963	0.614	476
OO	2	43	7.738	0.449	352
OO	3	43	7.223	1.375	525
OC	1	51	11.454	0.339	524
OC	2	51	11.775	0.185	657
OC	3	51	12.331	0.094	479

[1] WES sample designation (see Material and Methods).
[2] N.D. = not detected or below reportable detection limits.

Pore Water Extracts				
Sediment Sample	REP	Total SAL(ppt)	NH_3, mg/L	H_2S, mg/L
SC	1	32	16.0	100
SC	2	32	15.0	200
SC	3	32	10.1	100
PRR	1	34	22.5	0
PRR	2	34	21.5	0
PRR	3	34	22.0	0
AER	1	34	4.6	0
AER	2	34	4.8	0
AER	3	34	4.6	0
AMR	1	34	5.6	0
AMR	2	34	5.4	0
AMR	3	34	5.4	0
BFR	1	33	17.5	0
BFR	2	33	17.0	0
BFR	3	33	17.0	0
OI	1	30	11.0	0
OI	2	30	11.5	0
OI	3	30	11.0	0
OO	1	28	28.5	0
OO	2	28	29.0	0
OO	3	28	28.5	0
OC	1	32	42.0	0
OC	2	32	42.0	0
OC	3	32	42.5	0

Metals (mg/kg Dry Weight)							
Sediment Sample	**REP**	**AS**	**CD**	**CR**	**CU**	**PB**	**HG**
SC	1	9.37	0.88	46.5	35.0	26.5	N.D.
SC	2	9.26	0.92	47.0	38.4	28.7	N.D.
SC	3	8.85	0.90	44.3	32.2	23.7	N.D.
PRR	1	3.64	2.31	62.8	6.9	11.7	N.D.
PRR	2	4.02	2.33	57.9	7.0	13.1	N.D.
PRR	3	3.86	2.38	63.8	7.0	11.9	N.D.
AER	1	7.53	0.22	93.7	34.4	35.1	1.21
AER	2	7.41	0.24	76.3	31.5	35.1	1.30
AER	3	8.08	0.29	74.9	46.5	86.7	0.89
AMR	1	6.55	0.03	37.7	4.4	12.7	N.D.
AMR	2	6.22	0.02	32.6	6.5	13.3	N.D.
AMR	3	6.07	0.06	47.0	4.7	13.0	N.D.
BFR	1	6.00	0.24	87.4	45.1	39.2	0.36
BFR	2	5.83	0.22	87.9	44.7	43.7	0.36
BFR	3	5.86	0.24	84.1	44.0	41.6	0.36
OI	1	3.55	0.14	57.5	20.8	20.6	0.148
OI	2	3.35	0.13	56.0	22.4	20.9	0.247
OI	3	3.53	0.15	58.3	21.3	22.0	0.148
OO	1	6.84	0.27	82.7	40.4	38.3	0.247
OO	2	6.82	0.26	82.8	39.8	37.3	0.247
OO	3	7.15	0.28	85.9	40.8	39.4	0.361
OC	1	9.86	1.00	233	130	112.0	4.09
OC	2	9.73	1.02	220	139	155.0	4.00
OC	3	9.31	1.01	234	131	99.4	4.11

AS = ARSENIC CD = CADMIUM
CR = CHROMIUM CU = COPPER
PB = LEAD HG = MERCURY

N.D. = not detected or below reportable detection limits.

Metals (mg/kg Dry Weight)					
Sediment Sample	**REP**	**NI**	**SE**	**AG**	**ZN**
SC	1	42.6	0.81	0.20	84.3
SC	2	43.6	0.81	0.24	86.8
SC	3	39.8	0.76	0.21	78.2
PRR	1	40.2	0.27	N.D.	42.5
PRR	2	40.3	0.26	N.D.	41.6
PRR	3	41.6	0.28	N.D.	43.2
AER	1	74.6	0.26	0.21	80.6
AER	2	65.5	0.21	0.20	74.0
AER	3	69.2	0.21	0.23	75.1
AMR	1	30.9	N.D.	N.D.	23.0
AMR	2	30.9	N.D.	N.D.	24.8
AMR	3	33.2	N.D.	N.D.	24.3
BFR	1	83.8	0.28	0.42	114
BFR	2	83.7	0.31	0.39	111
BFR	3	84.2	0.30	0.39	114
OI	1	53.6	N.D.	0.13	50.5
OI	2	55.6	N.D.	0.14	52.7
OI	3	55.7	N.D.	0.10	51.6
OO	1	81.9	0.25	0.29	95.2
OO	2	81.0	0.24	0.29	132
OO	3	82.3	0.25	0.33	99.5
OC	1	120	0.33	0.75	260
OC	2	127	0.35	0.76	275
OC	3	180	0.36	0.72	266

NI = NICKLE ZN = ZINC
SE = SELENIUM
AG = SILVER

N.G. = not detected or below reportable detection limits.

Butyltin Concentrations (mg/kg Dry Weight)				
Sediment Sample	**REP**	**Mono-**	**Di-**	**Tri-**
SC	1	0.017	0.007	0.005
SC	2	0.017	0.007	0.006
SC	3	0.017	0.007	0.007
PRR	1	0.015	0.006	0.004
PRR	2	0.015	0.006	0.002
PRR	3	0.015	0.006	0.003
AER	1	0.015	0.007	0.009
AER	2	0.015	0.007	0.006
AER	3	0.015	0.007	0.008
AMR	1	0.015	0.006	0.002
AMR	2	0.015	0.007	0.000
AMR	3	0.014	0.006	0.001
BFR	1	0.016	0.007	0.006
BFR	2	0.015	0.013	0.007
BFR	3	0.016	0.007	0.004
OI	1	0.013	0.012	0.005
OI	2	0.013	0.011	0.014
OI	3	0.013	0.013	0.013
OO	1	0.013	0.000	0.004
OO	2	0.014	0.000	0.003
OO	3	0.014	0.000	0.005
OC	1	0.074	0.182	0.264
OC	2	0.074	0.188	0.277
OC	3	0.070	0.162	0.231

PAH Concentration (mg/kg Dry Weight)							
Sediment Sample	**REP**	**NAPHTH**	**ACENAY**	**ACENAP**	**FLUORE**	**PHENAN**	**ANTRAC**
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.	N.D.	0.99	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.	0.82	N.D.
AER	3	N.D.	N.D.	N.D.	N.D.	0.86	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	N.D.	N.D.	N.D.	N.D.	40.7	N.D.
OC	2	N.D.	N.D.	N.D.	N.D.	35.4	N.D.
OC	3	N.D.	N.D.	6.5	N.D.	37.8	N.D.

NAPHTH = NAPHTHALENE ACENAY = ACENAPHTHYLENE
ACENAP = ACENAPHTHENE FLUORE = FLUORENE
PHENAN = PHENANTHRENE ANTRAC = ANTHRACENE

N.D. = not detected or below reportable detection limits.

PAH Concentration (mg/kg Dry Weight)							
Sediment Sample	REP	FLANTHE	PYRENE	CHRYSE	BAANTHR	BBFLANT	BKFLANT
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	1.20	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	0.79	N.D.	N.D.	N.D.	N.D.
AER	3	0.85	1.71	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	43.9	27.9	11.7	7.7	11.5	N.D.
OC	2	33.7	28.3	9.7	6.4	9.8	N.D.
OC	3	39.0	24.5	10.0	6.7	9.6	N.D.

FLANTHE = FLUORANTHENE
PYRENE = PYRENE
CHRYSE = CHRYSENE
BAANTHR = BENZO(a)ATHRACENE
BBFLANT = BENZO(b)FLUORANTHENE
BKFLANT = BENZO(k)FLUORANTHENE

N.D. = not detected or below reportable detection limits.

PAH Concentration (mg/kg Dry Weight)					
Sediment Sample	REP	BAPYRE	I123PYR	DBAHANT	B-GHI-PY
SC	1	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.
AER	3	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.
OC	1	14.1	14.0	N.D.	14.1
OC	2	11.9	12.9	N.D.	12.3
OC	3	11.6	13.1	N.D.	10.4

BAPYRE = BENZO(a)PYRENE I123PYR = INDENO(1,2,3-C,D)PYRENE
DBAHANT = DIBENZO(A,H)ANTHRACENE B-GHI-PY = BENZO(G,H,I)PERYLENE

N.D. = not detected or below reportable detection limits.

Pesticides and PCBs (mg/kg Dry Weight)							
Sediment Sample	REP	ALDRIN	A-BHC	B-BHC	G-BHC	D-BHC	PPDDD
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	0.19	N.D.	N.D.	0.25	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

N.D. = not detected or below reportable detection limits.

Pesticides and PCBs (mg/kg Dry Weight)							
Sediment Sample	REP	PPDDE	PPDDT	HPTCL	DIELDRIN	ENDOI	ENDOII
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	0.0039	N.D.	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	3	0.0026	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	0.71	N.D.	0.56	N.D.	N.D.
OI	2	N.D.	N.D.	0.0017	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	0.039	N.D.	N.D.	N.D.	N.D.	N.D.
OC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

HPTCL = HEPTACHLOR DIELDRIN = DIELDRIN
ENDOI = A-ENDOSULFAN ENDOII = B-ENDOSULFAN

N.D. = not detected or below reportable detection limits.

Pesticides and PCBs (mg/kg Dry Weight)							
Sediment Sample	REP	ENDOSU	ENDRIN	ENDALD	HPTCLE	METOXYCL	TOXAPHEN
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	0.68	N.D.	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

ENDOSU = ENDOSULFAN SULFATE
ENDRIN = ENDRIN
ENDALD = ENDRIN ALDEHYDE
HPTCLE = HEPTACHLOR EPOXIDE
METOXYCL = METHOXYCHLOR
TOXAPHEN = TOXAPHENE

N.D. = not detected or below reportable detection limits.

Pesticides and PCBs (mg/kg Dry Weight)							
Sediment Sample	REP	PCB-1016	PCB-1221	PCB-1232	PCB-1242	PCB-1248	PCB-1254
SC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AER	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	1	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	2	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
OC	3	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

N.D. = not detected or below reportable detection limits.

Pesticides and PCBs (mg/kg Dry Weight)				
Sediment Sample	REP	PCB-1260	a-CHLRDN	g-CHLRDN
SC	1	N.D.	N.D.	N.D.
SC	2	N.D.	N.D.	N.D.
SC	3	N.D.	N.D.	N.D.
PRR	1	N.D.	N.D.	N.D.
PRR	2	N.D.	N.D.	N.D.
PRR	3	N.D.	N.D.	N.D.
AER	1	N.D.	N.D.	N.D.
AER	2	N.D.	N.D.	N.D.
AER	3	N.D.	N.D.	N.D.
AMR	1	N.D.	N.D.	N.D.
AMR	2	N.D.	N.D.	N.D.
AMR	3	N.D.	N.D.	N.D.
BFR	1	N.D.	N.D.	N.D.
BFR	2	N.D.	N.D.	N.D.
BFR	3	N.D.	N.D.	N.D.
OI	1	N.D.	N.D.	N.D.
OI	2	N.D.	N.D.	N.D.
OI	3	N.D.	N.D.	N.D.
OO	1	N.D.	N.D.	N.D.
OO	2	N.D.	N.D.	N.D.
OO	3	N.D.	N.D.	N.D.
OC	1	N.D.	N.D.	N.D.
OC	2	N.D.	N.D.	N.D.
OC	3	N.D.	N.D.	N.D.

a-CHLRDN = a-CHLORDANE
g-CHLRDN = g-CHLORDANE

N.D. = not detected or below reportable detection limits.

Appendix C
Water Quality Parameter Monitoring

Water Quality
Mean (SE) (N = 24) Water Quality Parameters During 70 Days of Exposure to Bedded San Francisco Bay Sediments

Sediment Sample	Temp. °C	Sal. ppt	D.O. mg/L	pH	Total NH_3, mg/L
SC	20.0 (0.2)	32.4 (0.1)	7.0 (0.1)	8.14 (0.02)	0.79 (0.26)
PRR	20.0 (0.1)	33.0 (0.6)	7.1 (0.1)	8.10 (0.04)	0.45 (0.15)
AER	20.0 (0.1)	32.6 (0.6)	7.0 (0.1)	8.10 (0.02)	0.12 (0.03)
AMR	20.0 (0.1)	32.3 (0.6)	7.1 (0.1)	8.04 (0.03)	0.16 (0.04)
BFR	20.0 (0.1)	32.5 (0.7)	7.1 (0.1)	8.16 (0.02)	0.13 (0.03)
OO	20.0 (0.1)	32.5 (0.7)	7.0 (0.1)	8.06 (0.03)	0.65 (0.29)
OI	20.0 (0.1)	32.9 (0.7)	7.1 (0.1)	8.06 (0.03)	0.17 (0.04)
OC	20.0 (0.1)	32.3 (0.7)	7.1 (0.1)	8.13 (0.03)	1.66 (0.57)

Water Quality
Mean (SE) (N = 60) Water Quality Parameters During Reproductive Monitoring

Sediment Sample	Temp., °C	Sal., ppt	D.O., mg/L	pH	Total NH_3, mg/L
SC	20.3 (0.1)	30.2 (0.1)	7.0 (0.1)	7.99 (0.02)	0.04 (0.01)
PRR	20.3 (0.1)	30.4 (0.1)	7.0 (0.1)	8.02 (0.02)	0.17 (0.06)
AER	20.3 (0.1)	30.4 (0.1)	7.1 (0.1)	8.05 (0.01)	0.07 (0.03)
AMR	20.3 (0.1)	30.4 (0.1)	7.0 (0.1)	7.99 (0.02)	0.03 (0.01)
BFR	20.3 (0.1)	30.3 (0.1)	7.0 (0.1)	8.06 (0.01)	0.03 (0.01)
OO	20.3 (0.1)	30.4 (0.1)	6.9 (0.1)	8.03 (0.02)	0.03 (0.01)
OI	20.3 (0.1)	30.3 (0.1)	7.0 (0.1)	8.00 (0.02)	0.07 (0.02)
OC	20.3 (0.1)	30.3 (0.1)	7.0 (0.1)	8.07 (0.02)	0.45 (0.15)

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1993	Final report

4. TITLE AND SUBTITLE
Chronic Sublethal Effects of San Francisco Bay Sediments on *Nereis (Neanthes) arenaceodentata*; Full Life-Cycle Exposure to Bedded Sediments

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
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3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper
D-93-2

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers, Washington, DC 20314-1000

U.S. Army Engineer District, San Francisco
211 Main Street, San Francisco, CA 94105-1905

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report is designed to address concerns regarding the potential chronic sublethal toxicity of San Francisco Bay sediments. To this end, the chronic sublethal effects of seven San Francisco Bay area sediments were evaluated in a full life-cycle exposure with the marine polychaete worm *Nereis (Neanthes) arenaceodentata*. Animals were exposed from early juvenile stage through production of a second generation. Test end points were survival, growth, and reproduction.

All test sediments were composites of several cores taken to project depth (38 ft (11.6 m) below mean low water mark) from a specific area. Reference sediments were collected from three potential in-bay disposal areas: on the mound at the Alcatraz disposal site, surrounding areas adjacent to the mound, the Bay Farm Borrow Pit in South Bay, and from an area outside the bay, Point Reyes. Project sediments were collected from three areas in Oakland Harbor: Oakland Inner Harbor; Oakland Outer Harbor, and from areas of Oakland Inner Harbor known to be contaminated, Oakland Contaminated. The control sediment was from Sequim, WA.

Survival could not be quantified because of early reproduction in some of the test sediments. Worm wet weights in all San Francisco Bay sediments were significantly depressed relative to controls. Similarly, reproduction was significantly lower for those worms exposed to Bay sediments relative to the control. Results of total Kjeldahl Nitrogen analysis suggest that differences in growth and reproductive output may have arisen from the poor nutritive value of the test sediments.

14. SUBJECT TERMS			15. NUMBER OF PAGES
Chronic sublethal	*Neanthes*	Sediment	52
Full life cycle	Reproduction	Toxicity	16. PRICE CODE
Growth	San Francisco Bay		

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		